Semiautomatic superimposition improves radiological assessment of curve flexibility in scoliosis

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Abstract: OBJECTIVE: Assessment of scoliotic curve flexibility and stiffness is essential for planning surgical treatment in adolescent idiopathic scoliosis (AIS). Measurement of curve flexibility is currently insufficiently precise. The purpose of this study was to introduce and validate a novel method of superimposing radiographs for more reliable measurement of curve flexibility. MATERIAL AND METHODS: Two independent radiologists measured Cobb angles separately on standard anterior-posterior (AP) (n = 48) and supine bending radiographs (n = 48), in patients with AIS, who were randomly included from a surgical database. The same readers repeated the measurements after the bending radiographs were semi-automatically superimposed on the AP radiographs by fusing the caudad end vertebra. Curve flexibility was calculated. Inter-reader agreement between the two independent readers was calculated using interclass correlation coefficient (ICC). RESULTS: A moderate inter-reader agreement was achieved in the upper curve (ICC = 0.57) and a good agreement in the lower curve (ICC = 0.72) with the standard method of assessing curve flexibility. With the use of the semiautomatic superimposition, however, almost perfect agreement was achieved for both the upper and the lower curves flexibilities (ICC = 0.93 and 0.97, respectively). CONCLUSION: The introduced semi-automatic superimposition technique for measurement of scoliotic curve flexibility in AIS is more precise and reliable than the current standard method. KEY POINTS: • A technique using semiautomatic superimposition of anterior-posterior and bending radiographs is introduced • Almost perfect agreement was achieved for scoliotic curves flexibilities measurements • This method is more precise and reliable than the current standard method.

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Abstract
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Material and methods Two independent radiologists measured Cobb angles separately on standard anterior-posterior (AP) ($n=48$) and supine bending radiographs ($n=48$), in patients with AIS, who were randomly included from a surgical database. The same readers repeated the measurements after the bending radiographs were semi-automatically superimposed on the AP radiographs by fusing the caudad end vertebra. Curve flexibility was calculated. Inter-reader agreement between the two independent readers was calculated using interclass correlation coefficient (ICC).
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Conclusion The introduced semi-automatic superimposition technique for measurement of scoliotic curve flexibility in AIS is more precise and reliable than the current standard method.
Key Points
- *A technique using semiautomatic superimposition of anterior-posterior and bending radiographs is introduced*
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- *This method is more precise and reliable than the current standard method*

Keywords Scoliotic curve flexibility · Superimposition · Radiographs · Superimposition of radiographs · Cobb angle

Introduction

Adolescent idiopathic scoliosis (AIS) is a relatively common disease with a prevalence of approximately 4.5 % [1, 2]. Surgical decision making in the treatment of AIS involves multiple factors that results in high variability among surgeons [3, 4]. Main causes are imprecision of curve measurements [5], variations in curve interpretation [6–9], and the surgeon's personal experience and preferences [4].

The Lenke classification, endorsed by the Scoliosis Research Society (SRS), was introduced to establish surgical treatment guidance according to the different appearances of the curves, using coronal and sagittal standing radiographs along with supine bending radiographs [9]. The cephalad and the caudad end vertebra are defined in standard anterior-posterior (AP) radiograph according to the SRS (www.srs.org) and the Cobb angle [10] is measured to define the major and minor curve, with the major curve defined by the largest measured Cobb angle. Furthermore, the curves are divided into structural and non-structural curve types dependent on the curve flexibility of the lateral bending radiographs. If the Cobb angle of the

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lateral bending radiograph towards the apex reaches an angle below 25° the curve is considered a non-structural curve. If an angle above 25° persists, the curve is considered a structural curve. These differentiations guide surgical decision making. According to Lenke et al, “the major and structural minor curves are included in the instrumentation and fusion and the nonstructural minor curves are excluded” [11].

While this classification has introduced a common guideline and advanced the understanding in surgical treatment of scoliosis, it is limited to AIS and, furthermore, the classification is based on final ability of the curve on lateral bending radiographs to reach 25°, but does not include the relative amount of curve flexibility (%), which can change the surgical technique and predict surgical correction [12, 13]. Therefore, not only the final ability of the curve to bend, but also total curve flexibility/stiffness should be considered in surgical decision making of scoliosis treatment. Curves are measured using Cobb angles, which have an inter-reader variance of up to 2–10° [5, 14–17], and therefore measurements are currently not sufficiently accurate and subject to inter-reader variability.

The aim of this study was to assess whether a radiographic technique that superimposes specific anatomical landmarks, such as the caudad end vertebra, will be more precise in measuring Cobb angle differences and thus in assessing curve flexibility.

Materials and methods

Study subjects

According to federal laws, no ethics board approval was needed for this retrospective study.

Twenty-seven patients with AIS (mean age±SD, 17.0± 5.7 years; 23 female, four male) were randomly included from a surgical database, which had a standard standing AP and a corresponding supine bending radiograph. The reason to include AIS patients was that in those patients bending radiographs are routinely performed and were available for this retrospective study. None of these patients were further excluded. However, in two patients (2/27) only the lower curve was completely imaged, not including the complete upper curve, and in four patients (4/27) only the upper curves were completely imaged, not including the complete lower curves on the bending radiographs.

Measurements “The cephalad end vertebra was defined according to SRS as the first vertebra in the cephalad direction from a curve apex whose superior surface is tilted maximally toward the concavity of the curve. In contrast the caudad end vertebra was defined as the first vertebra in the caudad direction from a curve apex whose inferior surface is tilted maximally toward the concavity of the curve” (www.srs.org).

Two independent radiologists (reader 1 with 6 years and reader 2 with >15 years of radiology experience) measured Cobb angles [10] between the cephalad and caudad end vertebra, as defined by SRS separately on standard standing AP radiographs and supine bending radiograph (bending toward the apex of the corresponding evaluated curve) using picture archiving and communication system (PACS) (Impax, Version 6.4.0.4551, Agfa-Gevaert, Mortsel, Belgium).

The same readers repeated the measurements using a novel custom-made software, which superimposes radiographs (ETH, Zurich, Switzerland). The bending radiograph was hereby semi-automatically superimposed on the AP radiograph by overlapping the caudad end vertebra with the use of three defined edge-points (Fig. 1). By fusing the two radiographs with this semi-automated superimposition method, it was more obvious for the readers to detect level height errors when measuring Cobb angles (Fig. 1). Furthermore, by using the superimposition technique, the caudad end vertebra was fused and the corresponding line for the angle measurement needed to be set only once (Fig. 1).

In total, each of the two readers had to measure 96 Cobb angles using the standard conventional technique and repeat them using the superimpose technique (Table 1). Further, in total 48 curve flexibility measurements were calculated for each technique.

Percentage Flexibility was calculated as [12]:

$$\text{Flexibility}\,\% = (\text{AP Cobb angle} - \text{bending Cobb angle}) / \text{AP Cobb angle} * 100\%$$

Statistical analysis The inter-reader agreement between the two independent readers was calculated using interclass correlation coefficient (ICC) using SPSS Statistics (Version 22.0.0.0, IBM). An ICC of 0.9–1 was considered as almost perfect agreement, an ICC of 0.7–0.89 as good, an ICC of 0.5–0.69 as moderate, and an ICC of <0.5 as low to weak.

Pearson’s correlation between the two readers was generated for angle measurements using PRISM (Version 6, Graphpad software, La Jolla, CA, USA). A correlation coefficient (r) >0.7 was considered as strong, 0.5–0.7 as moderate and <0.5 as low.

In addition a post-hoc power analysis was performed and demonstrated a significant power of >0.8.

Inter-reader agreement Overall precision in measurement of Cobb angles was sufficient using the standard or the here newly introduced semiautomatic superimposition technique (ICC=0.94 vs. 0.99, respectively, see Table 1).

However, quantification of overall flexibility was almost perfect with use of the semiautomatic superimposition technique (ICC=0.95) compared to the standard technique (ICC= 0.66) (Table 1). This difference is mainly explained by the

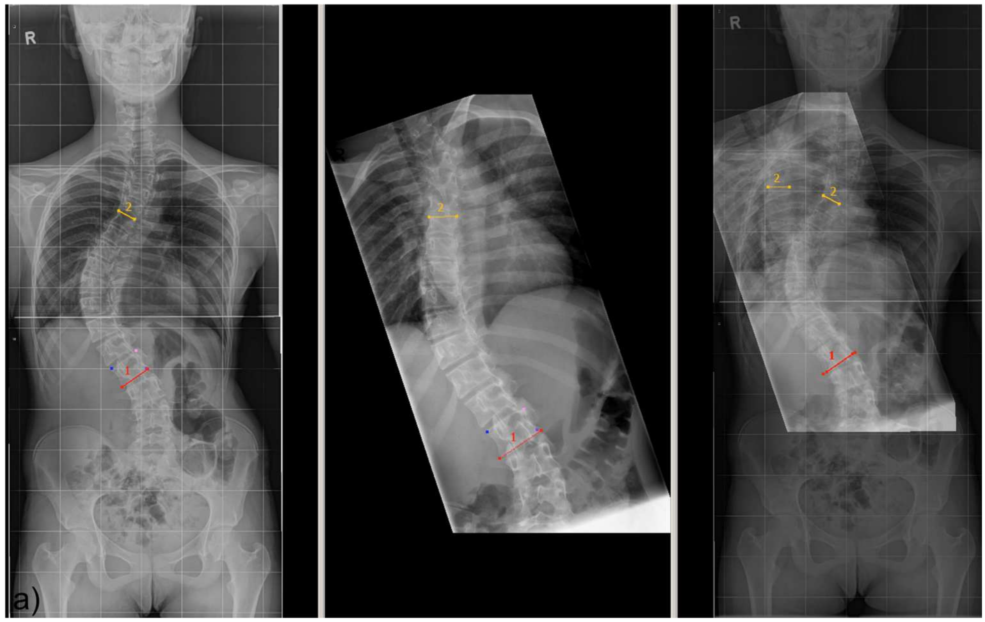

Fig. 1 Standard anterior-posterior (AP) radiograph of a adolescent idiopathic scoliosis (AIS) with a thoracic curve of 65° (**a**) that bends to 38° with convex bending (**b**). The superimposed figure (**c**) with the end vertebra fused on the AP and convex bending radiograph serves to control the measurement levels and the end vertebra angle

lower inter-reader agreements on Cobb angle measurements on the bending radiographs and was potentiated when subtracted from the AP radiographs (Table 1).

The superimposition technique also achieved a higher correlation of the total curve flexibility measurements (Fig. 2) and of the relative (percentage) curve flexibilities (Fig. 3) when compared to the standard technique between the two readers.

With use of this novel semi-automated superimposition technique, the images were superimposed in less than 1 min, the two Cobb angles measured, and the automatically generated flexibility angle provided.

Discussion

Not only the final ability of the curve to bend but also total curve flexibility/stiffness is important in surgical decision making of scoliosis treatment [18, 19]. A precise method to quantify the latter is introduced here with the method of superimposition of bending radiographs on standard AP radiographs.

To the best of our knowledge, this is the first report of an inter-reader agreement measuring curve flexibility. The inter-reader agreement accessing flexibility was much lower for the standard method of division of separately measured Cobb angles in the AP and bending radiographs, compared to the introduced superimposition technique. The increased reliability using the superimposed technique might be explained by three factors: first, the readers only need to set three angle lines instead of four to measure the two Cobb angles on the AP and lateral bending radiograph. Second, level height errors are obviously detectable and therefore eliminated, and third, the summations of errors due to the separately measured Cobb angles are diminished.

Table 1 Interclass correlation coefficients (ICC) measuring Cobb angles of the scoliotic curves using the standard method and the superimpose technique

	Curve	ICC using conventional radiographs (95 % CI)	ICC using the superimpose technique (95 % CI)
Overall Cobb angle measurements	Lower and upper (n=96)	0.94 (0.91-0.96)	0.99 (0.99-1.00)
Overall curve flexibilities: Difference AP-bending	Upper and lower (n=48)	0.66 (0.39-0.81)	0.95 (0.90-0.97)
Cobb angle measurements on AP radiographs	Upper (n=25)	0.98 (0.94-0.99)	0.97 (0.93-0.99)
	Lower (n=23)	0.95 (0.89-0.98)	0.99 (0.98-1.00)
Cobb angle measurements on bending radiographs (towards apex)	Upper (n=25)	0.82 (0.59-0.92)	0.99 (0.97-9.99)
	Lower (n=23)	0.88 (0.72-0.95)	0.99 (0.98-1.00)
Curve flexibilities: Difference AP-bending	Upper (n=25)	0.57 (0.01-0.81)	0.93 (0.84-0.97)
	Lower (n=23)	0.72 (0.35-0.88)	0.97 (0.92-0.99)

ICC, Interclass correlation coefficient; CI, confidence interval; AP, anterior-posterior; n, patient number

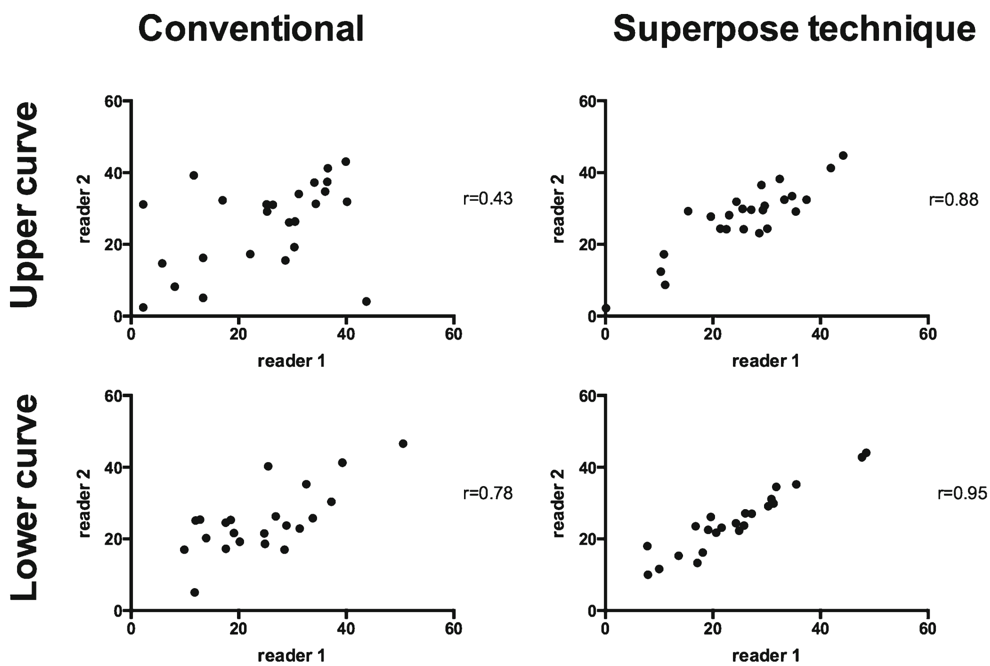

Fig. 2 Correlation of the subtraction of Cobb angle measurements (Cobb angles measured on anterior-posterior (AP) radiographs − Cobb angles measured on lateral bending radiographs) for the upper and the lower curves using the conventional technique in comparison to the herein introduced superimposed technique

Our inter-reader agreement measuring Cobb angles using the conventional method are in agreement with others [15, 17]. However in comparison to Goldberg et al. [17], who demonstrated lower agreement in assessment of the lower curve, we did not find any relevant difference between the reliability of Cobb angle measurements of the upper and the lower curve. This might be explained by the fact that the lower curves in this study did not have much smaller angles (mean± SD=37±11.5 degree) than the major curves (54±10 degree), while Goldberg et al. [17] reported lower curve angles of less than 20°.

Several methods are applied to asses flexibility, such as fulcrum flexibility percentage and traction radiographs performed under general anaesthesia [12, 18], but the most commonly performed technique is lateral supine bending which is also a milestone of the established Lenke classification. The presented radiological method of quantification of curve flexibility, however, could be applied to any kind of bending radiography.

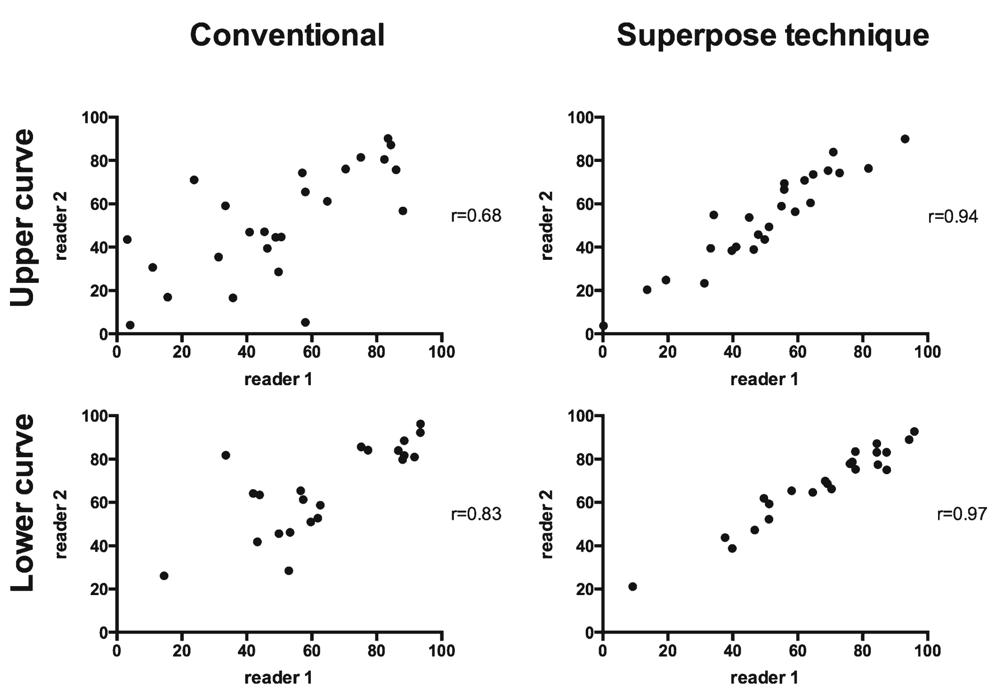

Fig. 3 Correlation of the percentage flexibility (=anterior-posterior (AP) Cobb angle – bending Cobb angle)/AP Cobb angle * 100 % [12]) for the upper and the lower curves using the conventional technique in comparison to the herein introduced superimposed technique

The percentage curve flexibility is not often clinically applied, but is important for surgical planning and predictability of surgical correction [12, 13, 18]. A stiff curve with only 10 % of correction on lateral bending is treated differently in surgery than a more flexible curve with 60 % of correction. While the former might need an anterior approach or osteotomies, the latter could be corrected by simpler posterior techniques. Therefore, it is important to have a precise tool to quantify flexibility preoperatively without reader errors. While such a technique has been validated here, it was not the aim of this study to assess the clinical importance of curve flexibility. Further research is needed to determine the importance of curve flexibility determination, but this method can help to diminish radiographical measurement errors.

However, certain limitations need consideration. The major limitation is that the presented patients do not represent a general population of patients with AIS as these were retrospectively included from a surgical database. However, the study did not focus on AIS but only used that patient population to be able to validate the introduced method. Second, bending radiographs of the smaller (minor) curves were not always present for all patients. This was mainly because if there was only a slight minor curve deformity, clinically, the necessity of a bending radiograph was not given, as this curve would be considered non-structural in any case. Therefore only larger lower curves had bending radiographs and this could be the cause of a higher inter-reader agreement of the lower curve compared to the results by Goldberg et al. [17]. Third, the software used is non-commercial and therefore not generally available. However, such a tool could easily be implemented in standard viewing software of main vendors. The authors think that the introduced technique of superimposition of two radiographs not only increases inter-reader agreement of curve flexibility, but might also be utilized to predict surgical correction rate and precisely assess curve progression.

Conclusion

The use of a semiautomatic superimposition technique for measurements of scolitic curve flexibility in AIS is more precise and reliable than the current standard method and reduces errors in measurement.

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